Extracorporial Knots in Laparoscopic Surgery: Which, When, and How

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Introduction:

Despite recent advances in both suture welding and knotless anchor technology, knot tying will remain a necessary skill which the surgeon must master when performing suture anchor in laparoscopic surgery. There are an endless number of combinations of knots (sliding versus static, simple versus complex, etc.) and suture types (monofilament versus braided) to accomplish this task. Surgeons are familiar with knotting but seem not to be aware of the possibilities and impact of the techniques of capsizing, flipping, and flyping knots. [1] *Capsizing* refers to changing or perverting a flat knot's geometry under asymmetric stress. The simplest examples of this is the change of the overhand knot into a half-hitch by putting more tension on its one end than on the other (Fig. 1A). [2,3,4] *Flipping* the knot means to interchange the standing part and working end of the suture, thereby relocating the knot from one end of the suture to the other.[5] The half-hitch can be flipped easily between both ends of a suture (Fig. 1B). *Flyping* (that rhymes with "typing") is an archaic Scottish word that was used to describe the peeling off of a very wet glove of the hand, thereby changes its configuration from a right-hand glove to a left-hand one. [6,7,8] .
The Scottish physicist Peter GuthrieTait (1831-1901) introduced flyping as a knotting term, in the late-19th century, to define this "turning outside in" deformation process of the geometry of knots. [9] An illustrative example of flyping is the change of a series of turns of the working end around the standing part, into the proper blood knot geometry by drawing the proximal turns over the distal ones (Fig. 1C). [7] Ignorance about the techniques of capsizing, flipping, and flyping resulted in the introduction of many allegedly new sliding endoscopic or arthroscopic knots that merely represented configurations of long-known fishing, sailing, or rigger knots. A knot should secure tissue approximation, simple, easy, quick, and reliable. The aim of this article review is to determine which hand tied knot configuration, suture size, and suture type that would be safe in laparoscopic surgery.

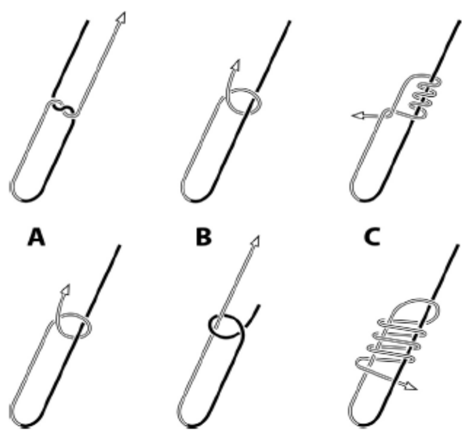

Figure 1. (A) Changing the overhand knot (top) into a half-hitch (bottom) by putting tension on one end is the simplest example of *capsizing* a knot. (B) *Flipping* a half-hitch from one end of the suture (top) to the other end (bottom). (C) Changing the sequence of turns of the working end around the standing part (top), into the proper Half Blood Knot geometry (bottom) is an example of *flyping*.

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Materials and Methods:

A literature review was performed using Springerlink, Pubmed, Highwire press, search engines like Google, and Yahoo. The following search terms were used: extracorporeal knot, laparoscopic knots, laparoscopic tissue approximation, Roeder's knot, Meltzer's knot, Weston knot, Duncan knot, Nicky's knot, SMC knot, Tennessee knot. 51032 citations were found. Selected papers were screened for further references. Publications that featured illustrations of sliding knots , comparing between different extracorporeal knots and suture materials, Knots tied with and without a series of 3 RHAPs. with statistical methods of analysis, were selected. More than 22 different sliding knots were used for this review (table 1).

Table 1. Different Sliding Knots in this Review

Two half-hitches [4]
Reversed half-hitches [4]
Practical knot (simple version) [10,11]
Practical knot (advanced version) [10]
Nicky's knot or taut-line hitch [12,13,14,15,16,17,18]
Giant knot [19]
Modified tautline hitch [18]
Tennessee slider [12,15,20,21,22]
Clinch knot, [23] Wendel Knoten,[24] and Vale knot [25]
Locking knot [26]
Secure knot [27]
Tonsillectomy knot [13]
Noose loop [28,29]
Duncan loop, [23] blood slipknot, [30] hangman's knot,[31] easy loop,[32] ordura knot [33]
Triad knot [34]
Three-twist knot [35]
Figure-of-eight noose [13]
Hangman's knot [13]
Hangman's tie [36]
Mid-ship knot [37]

Definitions

Post limb: the straight portion of the suture limb purely defined as the suture limb under the most tension
Wrapping limb: the free portion of the suture limb that wraps around the post limb
Effective knot: possesses the attributes of both knot security and loop security
Knot security: the effectiveness of a knot to resist slippage when load is applied
Loop security: the ability of a knot to maintain a tight suture loop as a knot is tied [38,39,40,41,42,43,44]

Knot Configurations

A. Half-Hitches

Half hitch is the simplest of all sliding knots formed by wrapping the suture limb once around the post limb. Named according to the position of the wrapping limb relative to the post limb as viewed by the surgeon during knot tying, (Figure 2).

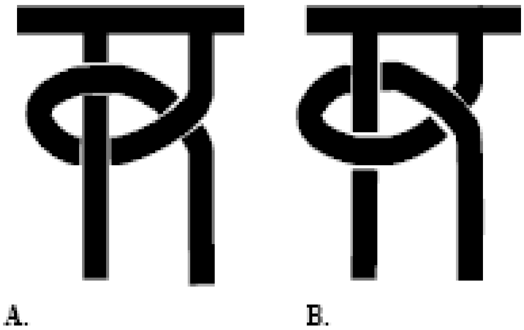


Figure 2. half hitches
(A. Under-over , B. Over- under)

Reversed half hitches refers to two sequential half hitches tied in reversed direction on the same post, (Figure 3).

Figure 3. Reversed half hitches on same post

Reversed half hitches on alternating posts (RHAP) refers to two sequential half hitches formed in reversed directions around the opposite post. RHAPs are commonly used to lock a sliding knot in place, (Figure 4). [38,39,40,41,42,43,44,45]

Figure 4. Reversing half-hitch and alternating posts

Two half-hitches as an extracorporeally tied sliding knot could be intracorporeally advanced, tightened, and pulled back to a flat granny knot during laparoscopic procedures (Fig. 5A). extracorporeally tied sliding reversed half-hitches equally could be reversed back intracorporeally to a flat square knot (Fig. 5B, Table 2). [4]

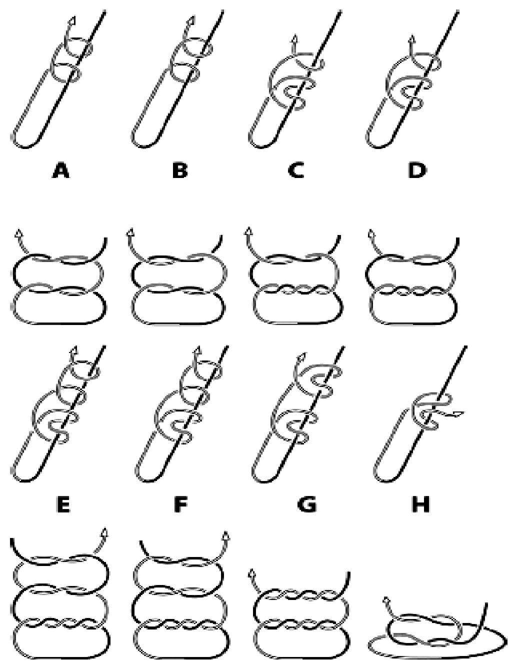


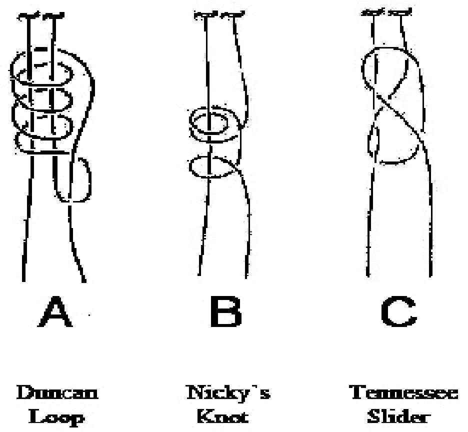
Figure 5. Numerous sliding knots (top row) represent the capsized geometry of flat knots (bottom row). Two half-hitches as such, are a capsized granny knot (A), reversed half-hitches a capsized square knot (B), the simple version of the practical knot a capsized surgeon's knot (C), Nicky's knot a capsized granny-wise surgeon's knot (D), the advanced version of the practical knot a capsized granny-wise surgeon's knot with an additional reversed half-hitch (E), and the giant knot a capsized grannywise surgeon's knot with an additional half-hitch (F). Equally, the modified taut-line hitch is a capsized granny-wise tree surgeon's hitch (G) and the Tennessee slider, a capsized whatknot (H). All these flat knots can also be capsized by tension on the left end instead of the right, but this will result in an identical capsized geometry.

Table 2. Flat Knots That Can Be Capsized Either Way* Into a Sliding Endoscopic Knot

Flat configuration	Sliding endoscopic knot
Granny knot	Two half-hitches
Square knot	Reversed half-hitches
Surgeon's knot (square style)	Practical knot (simple version)
Surgeon's knot (granny style)	Nicky's knot or taut-line hitch
Surgeon's knot (granny) + reversed half-hitch	Practical knot (advanced version)
Surgeon's knot (granny) + half-hitch	Giant knot
Tree surgeon's hitch (granny style)	Modified tautline hitch
Whatknot	Tennessee slider

*By putting more tension on either of the suture ends.

B. Commonly used compound sliding knots
Compound sliding knots have more than one turn of the wrapping limb around the post (i.e. any sliding knot other than a half hitch) (Figure 6). Can be used in situations where the suture slides smoothly and freely through the tissue and anchoring device. Advantageous since compound sliding knots can be made to slide down the post limb without unraveling or jamming prematurely. Theoretical disadvantages include abrasion of suture against the anchor eyelet, suture cutting through tissue as it slides. [46,47,48,49,50,51,52,53,54]



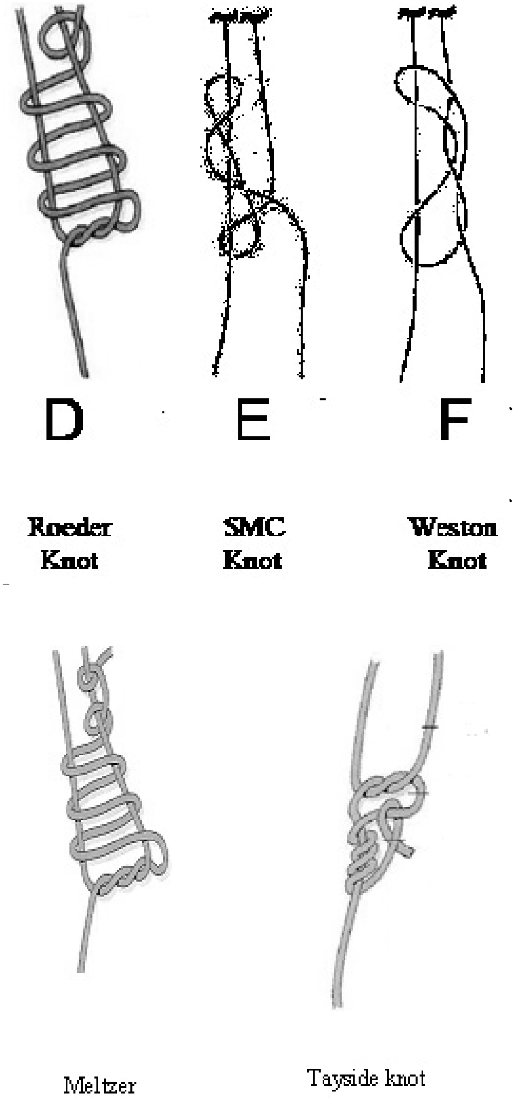


Figure 6. different types of sliding knots

C. Commonly used "non-sliding" (static) knots

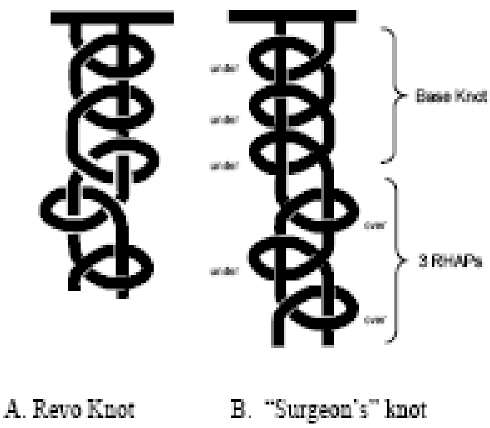


Figure 7. Non-sliding (static) knots

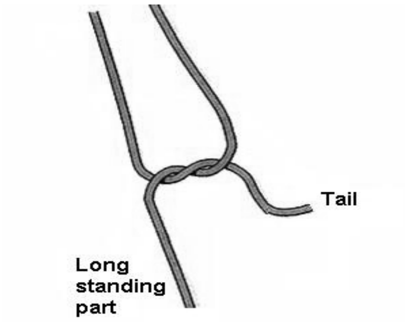
These knots are the only knots that can be used when the suture does not slide freely through the tissue and anchoring device. These knot configurations also theoretically avoid suture damage from abrasion and tissue damage during sliding, (Figure 7).

The major disadvantage of static knots is the propensity of the loop to loosen before the second half-hitch is seated to the point that it provisionally "locks" the knot. This occurs when using a single-lumen knot pusher.

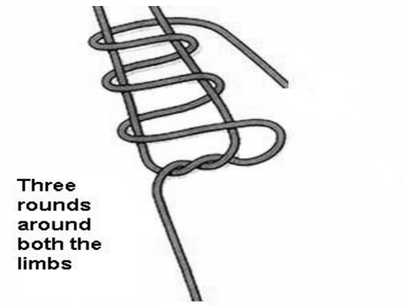
One method of minimizing this effect is by using a double-diameter knot pusher which holds the tissue loop tight as it advances sequential half-hitches (Surgeon's Sixth Finger). [55,56,57,58]

Roeder's Knot [59] *(Figure 8)*

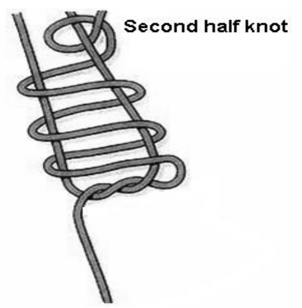
Step1. One half knot is taken first



Step2. Three rounds are taken in front of the first half knot , over both the limb of loop.



Step3: A second half knot is taken around one side of loop



Step4: Knot is stacked properly and then slide on the long standing part of the thread

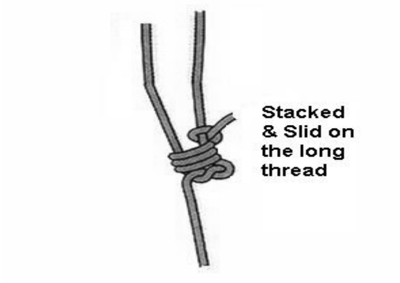
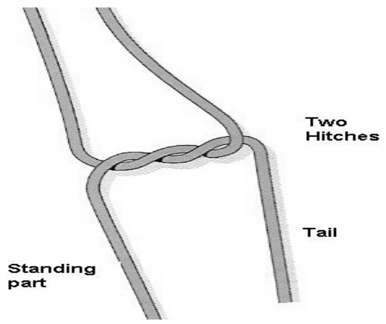


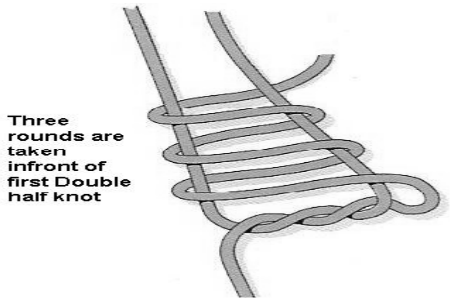
Figure 8. Roeder's knot (1:3:1, One hitch three winds and one locking hitch)

Meltzer slip knot *(59)* (Figure 9)

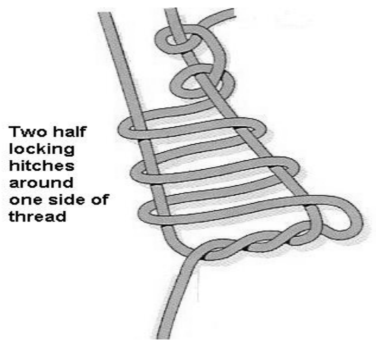
Step1. Two half knot is taken first



Step2. Three rounds are taken in front of the first double half knot over both the limb of loop.



Step3: Make two half hitches on the sliding strand of the loop.

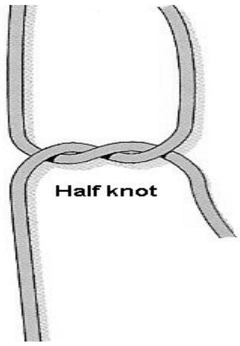


used instead of the Roeder knot to tie the medial end of the cystic duct during Cholecystectomy and to fix the cystic duct drainage cannula after trans-cystic clearance of ductal stones, as catgut is no longer available. PDS is the suture material of choice for Meltzer knot.

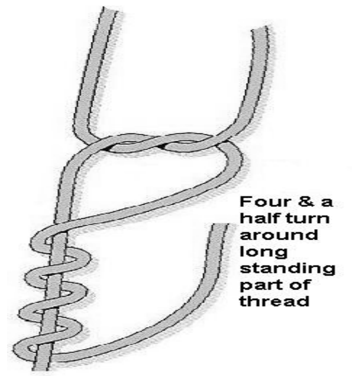
Figure 9. Meltzer knot (2:3:2, Two hitches, Three winds, Two half locking hitches, A slide)

Tayside knot *(59)* (Figure 10)

Step1: A single hitch (Half knot) is taken first



Step2. Four and a half rounds are taken behind the first half knot over long standing limb of thread.



Step3: A locking hitch is made by passing tail through the second and third loop.

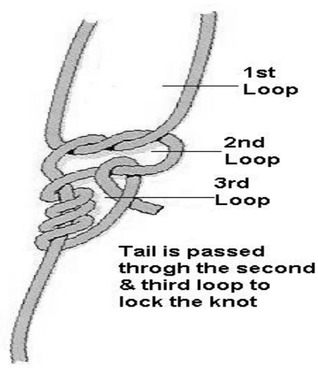
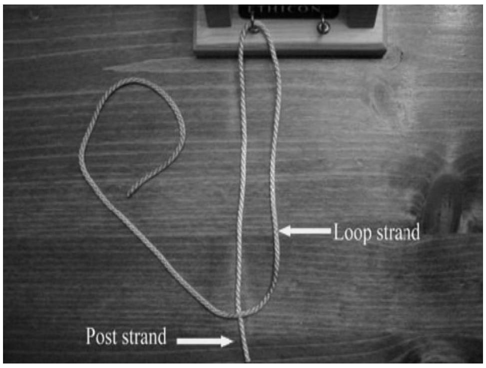
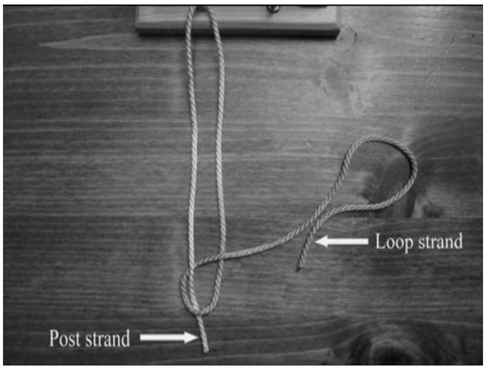


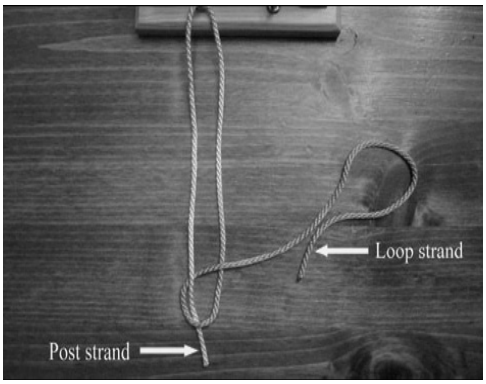
Figure 10. Tayside knot

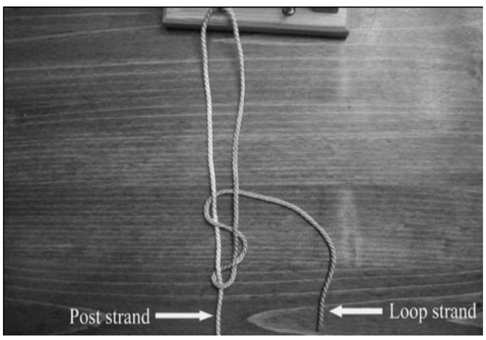
The Tayside knot is suitable for use with all braided sutures (2/0 or stronger) as well as dacron. It is used with Dacron for ligation of vessels such as the azygous vein, splenic artery/vein or the inferior mesenteric artery/vein.

Weston Knot [60, 61] (Figure 11)









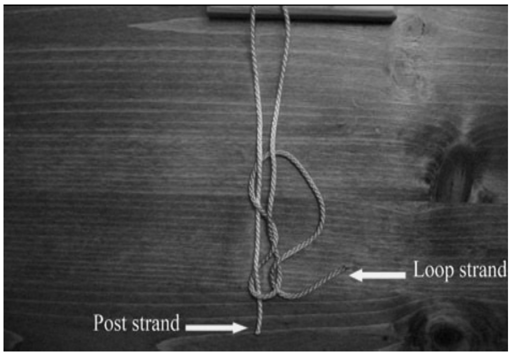


Figure 11. Weston Knot

The Weston slip knot was initially described in the obstetric and gynecology literature and is also used in arthroscopic surgery.The advantage of this knot is that it is relatively easy to tie outside, can then slip easily into place and be tightly secured. The post strand does not move throughout the knot; the loop strand is the longer strand which is moved to make the knot. The advantage of the Weston knot is that it locks readily and is not bulky.

Pre-tied loop (figure 12)

- The loop is drawn up into the metal sleeve.
- The tube is then introduced through an abdominal port.
- Once inside the abdomen the loop is advanced using the push rod.
- A grasping forceps is placed through the loop and used to grasp the tissue to be ligated.
- The loop is delivered over the tissue and the knot and push rod positioned at the base of the tissue.
- The loop is then tightened around the tissue by tensioning the long end and applying pressure to the knot via the push rod causing it to slide.
- The knot is locked firmly in place.
- The graspers are removed and replaced by suture scissors to divide the long end prior to removal

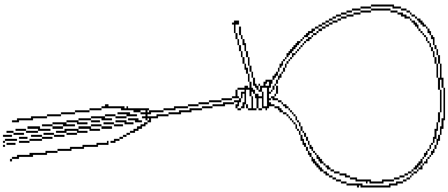


figure 12. Pre-tied loop

Preformed loops are used to ligate tissue e.g. the base of the appendix, lung bullae, and also useful for sealing a perforated organ if this is to be removed, e.g. perforation of the gallbladder during laparoscopic cholecystectomy where closure is necessary to prevent escape of gallstones into the peritoneal cavity. [59]

A pre-formed loop can also be used to secure a divided vessel after it has been isolated by a grasper. A slight modification of this technique allows it to be used to secure smaller identified vessels. One end is clipped and the other controlled temporally by a grasper, which has already been passed through a loop. The vessel is divided and the loop slid into place and tightened before the grasper releases the vessel. For Extracorporeal Knotting knot pushers are used. These knot pushers are of either closed jaw or of open jaw type, (figure 13).

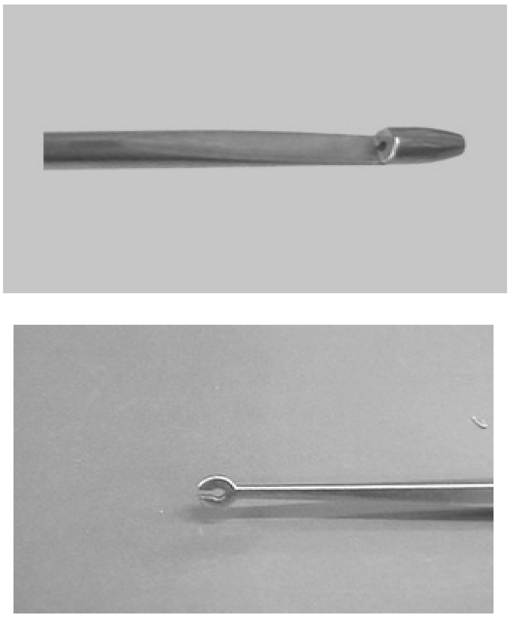


figure 13. knot pushers: closed jaw, open jaw

Extracorporeal knotting is preferred in the following situations:

- Ligature in continuity of large vessels
- Suturing in areas of limited access where the working space is restricted
- In the approximation of edges of defects where the force requires to approximate the edges is substantial [62]

Rules governing external slip knotting

- the type of the thread must be 1.5m and the guage should be 2/0 or greater
- The type of slip knot selected depends on the ligature material being used. Certain slip knots provide sufficient holding strength with catgut but not with other materials.
- For any ligature material, the holding force (resistance to reverse slipping) of any surgical slip knot varies directly with its caliber. Thus the holding strength of a 1/0 slip knot is roughly twice that of the 2/0 equivalent.
- Stiff hydrophobic monofilament material should be avoided as it exerts a lesser frictional hold and has a greater tendency to spill than braided. [62]

Suture material

Absorbable sutures: Catgut- Poor gliding ability, Vicryl- Good maneuverability, PDS- Excellent gliding ability, no need to follow during intracorporeal anastomosis. Non-absorbable sutures: Silk- it is braided and so more traumatizing, Prolene- Monofilament but has memory so makes it very tedious to use, Ethibond- Monofilament with less memory and better maneuverability than prolene [62]

Results:

Most surgeons suggest becoming facile with one static and one sliding knot. However, a static knot can actually be used in all situations whereby a sliding knot can be only used if the suture slides freely through the tissue and anchoring device. For a knot to be effective it must possess the attributes of knot security and loop security. Knot security depends on 3 factors: Friction , Internal interference, Slack between throws.

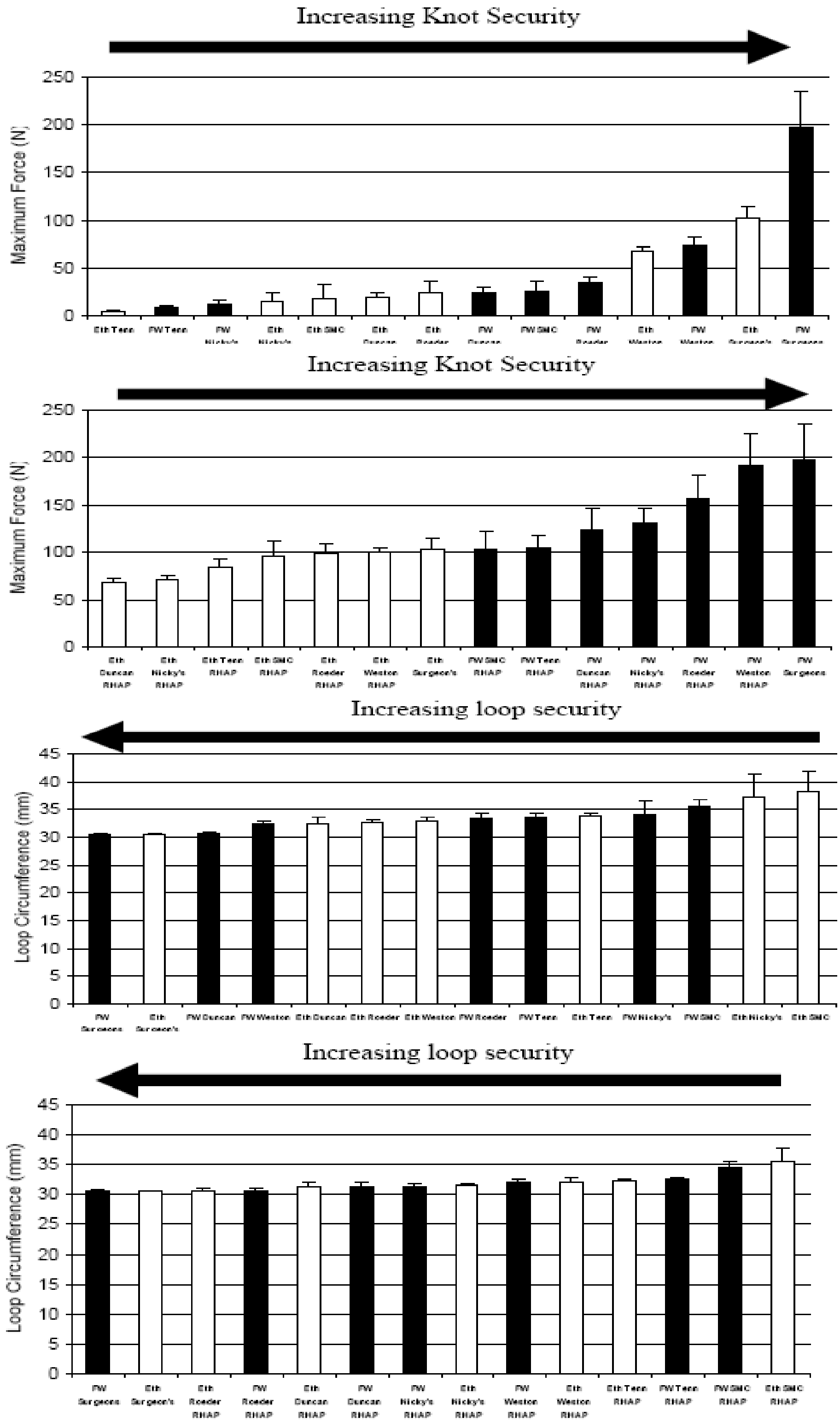
Friction is greater for braided multifilament suture than for monofilament suture.

Internal interference refers to the “weave” of the two suture limbs relative to each other. Internal interference can be increased by reversing the half-hitches and/or alternating posts. For compound sliding knots internal interference is increased by increasing the length of contact and the complexity of the “weave” between the two suture limbs.

Slack between throws is eliminated by removing twists between the suture limbs prior to advancing a half-hitch and by past-pointing.

Loop security is the ability to maintain a tight suture loop as a knot is tied, (Figure 14). It is possible to have an ineffective repair in spite of good loop security if the suture loop is loose and does not adequately approximate the edges of the tissue to be repaired.

Thus it is the knot which provides the best balance of loop security and knot security and can be easily and reproducibly tied. Loop security measured as loop circumference at 5 N preload. Knot security measured as maximum force to failure at 3 mm of crosshead displacement or suture breakage. (63,64,65,66,67,68,69,70,71,72,73,74)



Maximum force to clinical failure of sliding knots tied without RHAPs and the surgeon's knot using #2 Ethibond and #2 Fiberwire. Black = Fiberwire, White = Ethibond

Maximum force to clinical failure of sliding knots tied with 3 RHAPs and the surgeon's knot using #2 Ethibond and #2 Fiberwire. Black = Fiberwire, White = Ethibond.

Loop circumference of sliding knots without RHAPs and the surgeon's knot using #2 Fiberwire and #2 Ethibond. Black = Fiberwire, White = Ethibond

Loop circumference of sliding knots with 3 RHAPs and the surgeon's knot using #2 Fiberwire and #2 Ethibond. Black = Fiberwire, White = Ethibond

Figure 14. (44) Evaluated loop and knot security of 6 sliding knots (Duncan loop, Nicky's knot, Tennessee slider, Roeder knot, SMC knot, Weston knot) and 1 static knot (Surgeon's knot).

Compound sliding knots are commonly "locked" into place by tension the wrapping limb or "flipping" the knot. Tensioning the wrapping limb, distorts the post limb, resulting in a kink in the post, increasing the internal interference and thus increasing the resistance of the knot from backing off. Sliding knots are commonly divided into non-locking and locking knots. Locking knots may be further divided into proximal locking, middle locking and distal locking knots according to where the wrapping limb deforms the post limb when it is tensioned. Non-locking: Duncan loop, Proximal locking: Nicky's knot, Middle locking: SMC knot, Tennessee slider, Distal locking: Weston knot, Roeder knot.

Proximal locking knots are easy to lock especially when the loop tension is high. However, when locking some sliding knots, the loop tends to enlarge when "flipping" the knot. Proximal locking knots tend to cause more loop expansion (loss of loop security) than distal locking knots. Non-locking sliding knots (e.g. Duncan loop) resist slippage by the tight grip of the wrappings around the initial post. .[63,64,65,66,67,.68,69,70,71,72,73,74]

For externally tied slip knot a long length of ligature is required (100cm). It must be long enough to have the knot pusher threaded on to it, to be passed into the abdomen, round the structure to be ligated and to be brought out again and still have sufficient length for the surgeon to tie his / her knot. The knot chosen to complete the loop depends on the clinical situation and the material in use. modification of the Roeder knot was described in 1991 by Meltzer for use with PDS. The Tayside knot is safe for use with any braided material (2/0 or stronger). It supplies a degree of resistance to reverse slippage equivalent to a surgeons knot. [59]

The holding and tensile characteristics of the extracorporeal slip-knot depend on the types of ligature material used and the types of knot applied. Slip knots tied with silk and polyamide are less secure than the equivalent knots tied with dacron, lactomer and polydioxanone. [30]

Both static and cyclic loading studies have demonstrated that reversing post and alternating half-hitches following a base (i.e. compound sliding) knot is essential in providing both initial loop and knot security. Most compound sliding knots even newer knots (e.g. SMC) are more secure with RHAPs. RHAPs can be performed by manually switching and rethreading posts or by flipping a half hitch. This can be performed with single or double diameter knot pushers.[63,64,65,66,67,.68,69,70,71,72,73,74]

Discussion:

Laparoscopy is useful to treat surgical diseases, yet tying sutures in the cavity is a challenge. A knot to secure tissue approximation, which would be hand-made, secure, simple, easy, quick, reliable, and extracorporeal without extra mechanical devices constitute the essence of surgical practice because an unreliable suture knot can spoil the outcomes of an otherwise beautifully performed surgical procedure. Surgeons are certainly not new to knotting, but they seem not to be aware of the possibilities and impact of the techniques of capsizing, flipping, and flyping. Understanding these techniques provides endoscopic surgeons an insight into the evolution of sliding knots, and a simple technique to additional improvements on the knots they use. [1]

The surgeon's knot provided the highest force to failure and the tightest loop circumference whether tied with No. 2 Ethibond or No. 2 Fiberwire suture. Among the sliding knots, the Roeder knot with 3 RHAPs showed the best balance of loop security and knot security when tied with No. 2 Ethibond or No. 2 Fiberwire. Sliding knots tied without RHAPs showed low force to failure and loose suture loops whether tied with Ethibond or Fiberwire. The addition of 3 RHAPs improved knot security and, in most cases, loop security of all the sliding knots. [75]

The modified Roeder knot (by adding a fourth loop around the standing end of the suture and a second half-hitch to the completed knot.) was significantly stronger than the standard Roeder knot, and its comparable in strength to the strongest laparoscopic multiple-throw square knots. a 2 polydioxanone and 1 polyglyconate 4S modified Roeder knot would be an acceptable alternative to the commercially available Endoloop, followed by 0 polyglyconate that exceeded the 1PDS. [76, 77, 78, 79, 80]

Sterilization with either ethylene oxide or gas plasma of pre-tied, polyglyconate, or polydioxanone ligature loops significantly increases the in vitro likelihood of a modified Roeder knot untying. [81]

The load to ultimate failure reached plateau when 3 or more additional half-hitches were made for all knot configurations. As the number of additional half-hitches increased, the mode of failure switched from pure loop failure (slippage) to material failure (breakage). [82, 83, 84]

Measurements of knot strength of two to six half hitches (hand tied) showed that four half hitches were necessary to tie a secure nonslipping knot with most monofilament threads (nylon, polytetrafluoroethylene, braided polyester suture, and polyamide 66), while three half hitches were adequate to secure a knot when polyglactin 910, braided polyester fiber, silk, and polydiaxone were used. Additional throws did not increase knot strength once the knot no longer slipped. Improvements in knot strength at laparoscopy can be achieved by choice of optimal knot configuration for different suture materials. [85, 86]

Conclusion:

A static surgeon's knot provides the best balance of loop security and knot security within the knot configurations. A sliding knot without RHAPs has both poor loop security and knot security and should not be tied. The addition of 3 RHAPs improves knot security of all sliding knots tested and improves the loop security of most of the sliding knots tested. Loop security is a primary determining factor. The knot chosen should be the one which the surgeon can easily and reproducibly tie with good knot and loop security.

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